

IFS, AN INTERACTIVE FOREST SIMULATOR FOR LONG RANGE PLANNING

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A computer program to simulate forest plantation management in an interactive manner is described. It has been implemented in BASIC for ICL 2980, Radio Shack TRS-80, and Tektronix 4051 computers.

INTRODUCTION

Linear Programming (LP) and Simulation are two of the most popular tools for forest planning. Linear Programming models, such as CPLAN (Shirley 1979), produce an optimal solution for a specific representation of the planning problem. This representation, however, usually involves a considerable simplification of the management objectives and constraints. Many of the factors and considerations which are relevant to the selection of a plan may not be easily represented by an LP model or may be subjective or difficult to quantify. The same is true for other optimisation models.

Simulation models are used to explore the consequences of alternative management plans. Management strategies can be tested and assessed from different viewpoints. However, it is feasible to test only a few of the infinity of possible plans, and the alternative selected might be much inferior to others not examined.

Optimisation and simulation, then, should be considered as complementary rather than competitive approaches. An optimisation model may be used to obtain the best plan according to some criterion. Usually the optimum is rather flat, with different alternatives giving similar values for the objective function. Simulation may then be used to explore the decision space around the "optimum" solution. Consideration can be given to trade-offs between the value of the objective function and other factors which are difficult to incorporate into a formal optimisation model.

Most simulation programs for forest planning run in batch mode. This means that the user must specify in advance all actions to be taken up to the planning horizon. The user then submits this strategy to the computer and waits for a printout showing the results. The plan can then be altered and the cycle repeated. In addition to being time consuming, this approach lacks flexibility. There is a need for interactive simulation systems where actions are specified as the simulation advances through time.

IFS is a computer program, written in BASIC, for interactively simulating forest plantation management. IFS stands for Interactive Forest Simulator, and also reflects the purpose of providing answers to "what if" questions. It is operated in a conversational

mode from a remote computer terminal or on a stand-alone microcomputer. Several versions of IFS have been in use by New Zealand Forest Service since June 1979, and have become very popular for the evaluation of cutting schedules at the forest, regional, and national levels. The current version, IFS/2, incorporates several improvements suggested by this experience, and has been implemented on an ICL 2980 computer and on Radio Shack TRS-80 and Tektronix 4051 microcomputers. Versions for a PDP-11, in BASIC-11 and in BASIC-Plus, are under development.

A discussion of the representation of the forest which is used in IFS is presented under "Forest model" below; the use of the simulator is briefly described under "Simulation" and this section is followed by an example of simulation. Some of the details under "Simulation" and "Example" are specific to the ICL 2980 implementation; there are minor differences in the implementations for the other computers. Some aspects of the uses of relative increments in IFS are discussed in Appendix 1.

FOREST MODEL

The representation of the forest in IFS is similar to that commonly used in the preparation of cutting schedules by hand and in other computer simulators. The forest is described by a cross-classification of areas into crop types and age classes. Crop types are groups of stands which are assumed to grow according to a common yield table. Stands may also be segregated into different crop types according to characteristics relevant to the planning exercise, such as location, ownership, harvesting requirements, etc. The simulation advances by time intervals (periods) of length equal to the number of years in each age class.

Fig. 1 shows a simple example with just one crop type and 7 age classes. At the beginning of each period the state of the forest is described by the area in each age class. Some of the area in each class may be cut, and the remaining area moves into the next age class for the next period. The harvested areas may be replanted immediately or left unplanted. The areas cut from each age class are multiplied by the appropriate entry in a yield table in order to compute the volume produced in the period.

The situation where there are several crop types is entirely analogous (Fig. 2). Areas remaining after cutting move into the next age class in the same crop type. Areas harvested may be replanted with different crop types.

The areas or volumes to be cut in each period can be specified in a variety of ways, described in the next section. Various reports about the current state of the forest and about cutting and planting can be produced. In addition to the yield tables shown in Figs 1 and 2, tables containing values per hectare for up to 4 different products can be included for use in the cutting reports (instead of products these values may represent consumption of resources such as labour, machinery, etc.). Thinning yields (for up to 5 products) are multiplied by the areas remaining after harvesting in the appropriate crop type and age classes in order to produce a thinning report.

Before a simulation can be started, the initial state of the forest, the yields, and the optional product and thinning information must be stored in the computer. These data may be entered from the keyboard, from punched cards, or be generated by other programs, and are stored in several files in free format.

Fig. 3 shows the input data to be used in the example below. The first file, IFS.TESTAREAS, contains the number of crop types (3), number of age classes (7), age

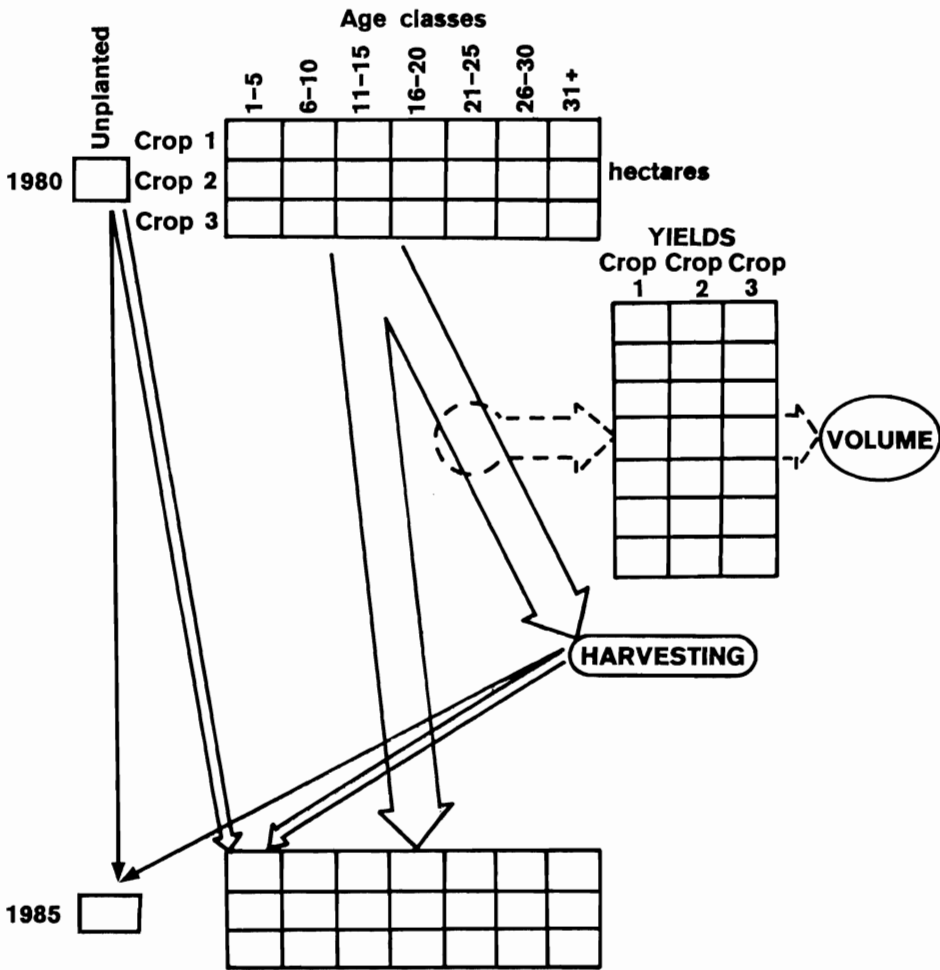


FIG. 1—Flow of areas. One crop type.

class width (5), base year (1980), the crop type names, and the area (in hectares) in each crop type and age class. File IFS. TESTYIELDS contains the yields (in m³/ha) for each crop type and age class. File IFS. TESTPRODS specifies the names of three products, each followed by the yield (in units/ha) for each crop type and age class. Finally, file IFS. TESTTHINNINGS contains the thinning information: number of crop/age classes thinned (4), number of products (2), product names, and then, for each crop/age class which is thinned, the crop type number, age class number, yield for product 1, and yield for product 2 (units/ha).

It is important to realise that the ages are ages at the beginning of a period, but cuts and thinnings will be performed within the period while the stands are moving into the next age class. The yield data should be prepared taking this effect into consideration.

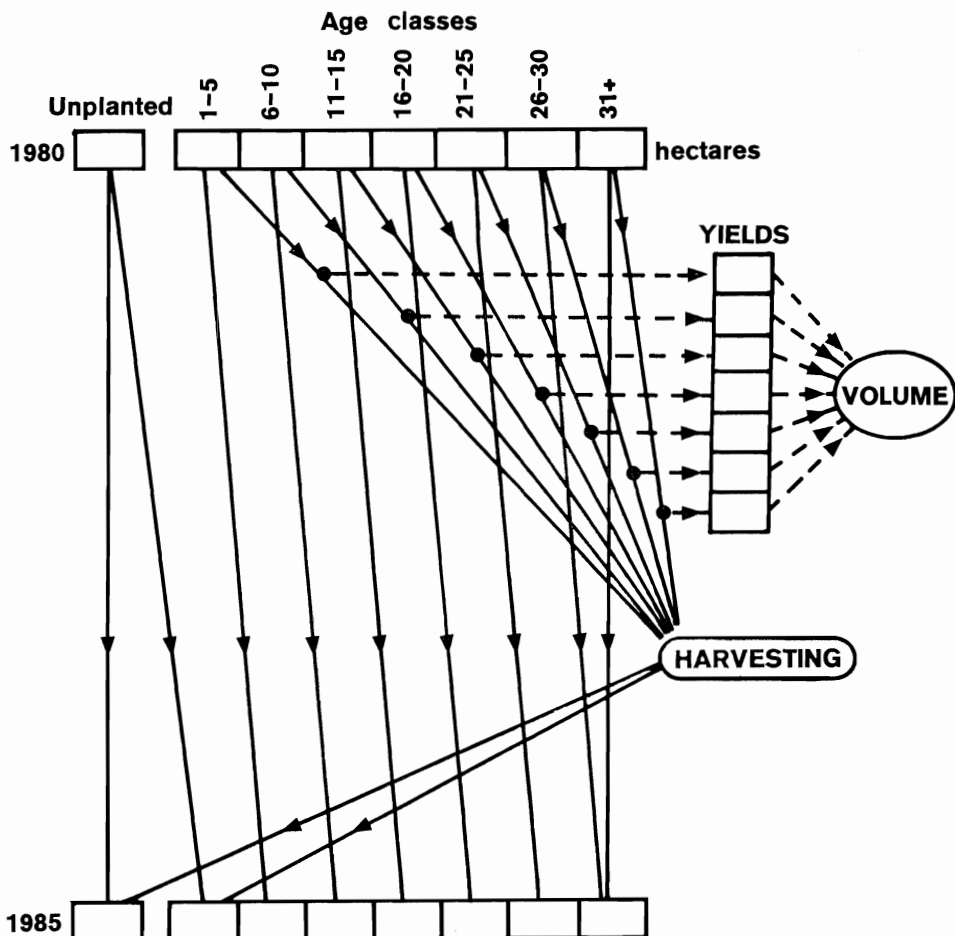


FIG. 2—Flow of areas. Three crop types.

SIMULATION

The program runs conversationally, prompting the user for input and describing the operations performed. After entering the names of the data files, the simulation is controlled through a number of commands which can be invoked in any order, any number of times. The commands are identified by mnemonic names (only the first two characters are significant), and may be conveniently classified into four groups:

(1) Control: These commands deal with the over-all control of the simulation.

ADVANCE. This command causes the simulation to advance to the next period.

SCRATCH. This command cancels all cuts and plantings performed during the current period, to enable other options to be attempted.

SAVE. With this command it is possible to save the status of the forest at any point through the simulation. The simulation can then be restarted from that point at a later time.

File IFS.TESTAREAS

3 , 7 , 5 , 1980

GOOD , AVERAGE , POOR

4406 , 2008 , 1015 , 1449 , 2123 , 1545 , 461

5696 , 2596 , 1312 , 1814 , 2567 , 1905 , 604

5633 , 2567 , 1298 , 1666 , 2136 , 1684 , 618

File IFS.TESTYIELDS

0 , 153 , 306 , 463 , 663 , 864 , 1064

0 , 110 , 220 , 333 , 477 , 622 , 766

0 , 69 , 139 , 210 , 301 , 393 , 484

File IFS.TESTPRODS

PEELERS

0 , 8 , 26 , 44 , 68 , 92 , 115

0 , 4 , 17 , 31 , 48 , 65 , 81

0 , 2 , 10 , 18 , 29 , 40 , 50

SAWLOGS

0 , 31 , 103 , 178 , 271 , 366 , 460

0 , 17 , 69 , 123 , 191 , 259 , 325

0 , 6 , 39 , 74 , 116 , 160 , 201

PULPLOGS

0 , 115 , 177 , 241 , 325 , 406 , 489

0 , 89 , 134 , 180 , 239 , 299 , 360

0 , 61 , 90 , 118 , 157 , 193 , 232

File IFS.TESTTHINNINGS

4 , 2

"PULP, cu m" , "SAWLOGS, cu m"

1 , 3 , 45 , 5

1 , 5 , 120 , 30

2 , 4 , 50 , 10

3 , 4 , 45 , 5

FIG. 3—Example of input files.

COMMANDS. Displays the list of commands available.

END. Ends the simulation.

- (2) Reports: These commands display information about the forest. They have no effects on the simulation.

AREP (area report). This command displays a table of the current areas by crop types and age classes, including totals.

SSUM (status summary). This command displays the current area, volume, average age, and minimum relative increment for each crop type (the relative increment is the annual volume increment as a percentage of the standing volume — see Appendix 1).

CSUM (cuts summary). This command displays the area, volume, and average age for the cuts performed in the current period, for each crop type. New planted areas are also shown. If data on yields for different products have been provided, a table with the amount of each product obtained from each crop type is produced also.

CREP (crop report). This command displays detailed information about the current status of a particular crop type. It shows, for each age class, the areas and volumes that were available at the start of the period, those that have been cut, and the current residual area and volume.

THREP (thinning report). Displays thinning information for the period if a thinning data file has been provided.

- (3) Actions: These commands are used to specify cuts and new plantings. They have a cumulative effect until SCRATCH or ADVANCE are used.

CCUT (class area cut). This command causes a given area to be cut from a specified crop type and age class. It may also be used for adding area by specifying a negative area to be cut (useful, for example, in case of purchases, or for transferring stands from one crop type to another).

PCUT (percentage cut). Analogous to CCUT, but the cut is specified as a percentage.

CVCUT (crop volume cut). This command causes a specified volume to be cut from a given crop type. This volume is made up by the program by cutting the oldest age classes first (oldest-age priority).

CACUT (crop area cut). Analogous to CVCUT, but an area to be cut is specified instead of a volume.

OCUT (oldest ages cut). This command causes a specified volume to be cut from all crop types, using oldest-age priority. For a same age the priority is according to order in the list of crop types.

VCUT (volume cut). This command causes a specified volume to be cut from all crop types, using minimum relative increment priority as follows. The relative increments of the oldest non-empty age class for each of the crop types are compared and the class with the smallest value is selected. The required volume is then cut from this class. If there is not enough volume in the class selected the whole class is cut and the process is repeated until the specified volume is obtained or the forest is exhausted.

The allocation of the cut to crop types according to the relative increments is optimal in the sense that the growth of the remaining stands is maximised (see Appendix 1).

ACUT (area cut). This command causes a specified area to be cut using a procedure analogous to that used for VCUT.

RCUT (relative increment cut). Crop/age classes with relative increments less than a specified value are cut. See Appendix 1 for applications of this command.

PLANT. This command is used to specify areas to be planted in given crop types. The areas are added to the first age class in the next period. It can be used with negative values for withdrawing land from production or for reallocating the planting among crop types.

- (4) Action modifiers: These commands affect the operation of some of the action commands.

MASK. Crop/age classes can be "masked" using this command. Classes that have been masked are not available for cutting when using the commands CVCUT, CACUT, OCUT, VCUT, ACUT, or RCUT.

UNMASK. This command removes any maskings from specified crop/age classes.

REPLANT. By default, all areas cut are automatically replanted into the same crop type. This command allows cuts from any crop type to be re-allocated for replanting into any other crop type. The command may also be used for displaying the current allocation.

This is only a brief description of the functions of the different commands. Additional details may be gathered from the examples in the next section. A full description and program listings are available from the author.

EXAMPLE

The following example attempts to show most of the facilities available in IFS/2. The input data of Fig. 3 were used. Items typed by the user are underlined, and comments have been added in a different typeface.

: RUN IFS.VERSION2

* IFS.VERSION2 05 FEB 81 17:00:10

IFS/2 - INTERACTIVE FOREST SIMULATOR
 =====

Name of the file containing the areas? IFS.TESTAREAS

NUMBER OF CROP TYPES: 3
 NUMBER OF AGE CLASSES: 7
 AGE CLASS WIDTH: 5
 BASE YEAR: 1980

Name of the file with the yield tables? IFS.TESTYIELDS
 Name of file with the products/resources data (enter NONE if
 this option is not used)? IFS.TESTPRODS
 Name of the file with the thinning data (enter NONE if this
 option is not used)? IFS.TESTTHINNINGS

Proceed with the simulation by entering commands.
 The commands available are:

COMMAND	DESCRIPTION	COMMAND	DESCRIPTION
-----	-----	-----	-----
CCUT	Class area cut	PCUT	Percentage cut
CVCUT	Crop volume cut	CACUT	Crop area cut
OCUT	Oldest ascs cut	RCUT	Rel.Incr.cut
VCUT	Volume cut	ACUT	Area cut
MASK	Mask	UNMASK	Unmask
PLANT	New Plantings	REPLANT	Replanting allocation
AREP	Area report	CREP	Crop report
SSUM	Status summary	CSUM	Cuts summary
THREP	Thinning report	SCRATCH	Scratch
ADVANCE	Advance to next period	SAVE	Save
COMMANDS	Commands list	END	End

Only the first two characters of each command are significant.
 Use REPLANT to read the replanting allocation file, if any.

Command? AREP
 Area report

PERIOD 1980 - 1984

Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES							TOTAL
	3	8	13	18	23	28	33	
GOOD	-4406	2008	1015	1449	2123	1545	461	13007
AVERAGE	-5696	2596	1312	1814	2567	1905	604	16494
POOR	-5633	2567	1298	1666	2136	1684	618	15602
TOTAL	15735	7171	3625	4929	6826	5134	1683	45103

age classes identified by midpoints

Command? CCUT
 Class area cut
 Crop type? AVERAGE

Age class? 23 any age within the age class will do
 2567 ha and 1224459 cu.m. in age class 23 of crop type AVERAGE
 Area to be cut (ha)? 800
 800 ha. and 381600 cu.m. cut
 1767 ha. remains.

Command? CVCUT
 Crop volume cut
 Crop type? POOR
 Volume (cu.m.)? 1250000
 299112 cu.m. and 618 ha. cut from crop type POOR; age class 33
 661812 cu.m. and 1684 ha. cut from crop type POOR; age class 28
 289076 cu.m. and 960.385 ha. cut from crop type POOR; age class 23
 READY

Command? AREP
 Area report

PERIOD 1980 - 1984

Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES							TOTAL
	3	8	13	18	23	28	33	
GOOD	-4406	2008	1015	1449	2123	1545	461	13007
AVERAGE	-5696	2596	1312	1814	2567	1905	604	16494
POOR	-5633	2567	1298	1666	2136	1684	618	15602
TOTAL	15735	7171	3625	4929	6826	5134	1683	45103

Command? CSUM
 Cuts summary

PERIOD 1980 - 1984

CROP TYPE	AREA,ha	VOLUME,cu m	AVG.AGE	NEW PLANTING
GOOD	0	381600	23	0
AVERAGE	800	1.25 E+6	27.4753	0
POOR	3262.39	1.6316 E+6	26.5939	0
TOTAL	4062.39			

CROP TYPE	PEELERS	SAWLOGS	FULPLOGS
GOOD	0	0	0
AVERAGE	38400	152800	191200
POOR	126111.	505063.	617169.
TOTAL	164511.	657863.	810369.

Command? SSUM
 Status summary

PERIOD 1980 - 1984

CROP TYPE	AREA,ha	VOLUME,cu m	AVG.AGE	MIN.REL.INCR
GOOD	13007	4521634	13.5205	0
AVERAGE	15694	3668695	12.8378	0
POOR	12339.6	1061265	9.02266	5.47881
TOTAL	41040.6	9251594	11.9071	

Command? CREP
 Crop report
 Crop type? POOR

PERIOD 1980 - 1984 CROP TYPE POOR NEW PLANTING: 0 ha

Areas in ha, volumes in 1000 cu m.

AGE CLASS	AGE RANGE	INITIAL AREA	INITIAL VOLUME	CUTS AREA	CUTS VOLUME	RESIDUAL AREA	RESIDUAL VOLUME	MASKING
3	1-5	5633	0	0	0	5633	0	-
8	6-10	2567	177	0	0	2567	177	NO
13	11-15	1298	180	0	0	1298	180	NO
18	16-20	1666	350	0	0	1666	350	NO
23	21-25	2136	643	960	289	1176	354	NO
28	26-30	1684	662	1684	662	0	0	NO
33	31-35	618	299	618	299	0	0	NO
TOTAL		15602	2311	3262	1250	12340	1061	

Command? THREP
Thinning report

CROP TYPE	AGE CLASS	AREA, ha	PULP, cu m	SAWLOGS, cu m
GOOD	11 - 15	1015	45675	5075
GOOD	21 - 25	2123	254760	63690
AVERAGE	16 - 20	1814	90700	18140
POOR	16 - 20	1666	74970	8330
TOTAL		6618	466105	95235

Command? VCUT

Volume cut

Volume (cu.m.)? 5000000

490504 cu.m. and 461 ha. cut from crop type GOOD, age class 33
462664 cu.m. and 604 ha. cut from crop type AVERAGE, age class 33
1334880 cu.m. and 1545 ha. cut from crop type GOOD, age class 28
1184910 cu.m. and 1905 ha. cut from crop type AVERAGE, age class 28
1407549 cu.m. and 2123 ha. cut from crop type GOOD, age class 23
119493 cu.m. and 250,509 ha. cut from crop type AVERAGE, age class 23
MIN.RELATIVE INCREMENT IS NOW 5.4519 %

Command? VCUT

Volume cut

Volume (cu.m.)? 50000000

723366 cu.m. and 1516.49 ha. cut from crop type AVERAGE, age class 23
353840 cu.m. and 1175.61 ha. cut from crop type POOR, age class 23
670887 cu.m. and 1449 ha. cut from crop type GOOD, age class 18
604062 cu.m. and 1814 ha. cut from crop type AVERAGE, age class 18
349860 cu.m. and 1666 ha. cut from crop type POOR, age class 18
180422 cu.m. and 1298 ha. cut from crop type POOR, age class 13
310590 cu.m. and 1015 ha. cut from crop type GOOD, age class 13
288640 cu.m. and 1312 ha. cut from crop type AVERAGE, age class 13
307224 cu.m. and 2008 ha. cut from crop type GOOD, age class 8
285560 cu.m. and 2596 ha. cut from crop type AVERAGE, age class 8
177123 cu.m. and 2567 ha. cut from crop type POOR, age class 8
FOREST EXHAUSTED. DEFICIT = 45748406 cu.m.

Command? AREP

Area report

PERIOD 1980 - 1984

Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES						TOTAL	
	3	8	13	18	23	28		33
GOOD	-4406	0	0	0	0	0	0	4406
AVERAGE	-5696	0	0	0	0	0	0	5696
POOR	-5633	0	0	0	0	0	0	5633
TOTAL	15735	0	0	0	0	0	0	15735

classes with zero yield were not cut

Command? SCRATCH

Scratch

back to the initial status:

Command? AREP

Area report

PERIOD 1980 - 1984

Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES						TOTAL	
	3	8	13	18	23	28		33
GOOD	-4406	2008	1015	1449	2123	1545	461	13007
AVERAGE	-5696	2596	1312	1814	2567	1905	604	16494
POOR	-5633	2567	1298	1666	2136	1684	618	15602
TOTAL	15735	7171	3625	4929	6826	5134	1683	45103

Command? RCUT

Rel.Incr.cut

Target relative increment (%)? 5

461 ha. and 490504 cu.m. cut from crop type GOOD, age class 33
1545 ha. and 1334880 cu.m. cut from crop type GOOD, age class 28
604 ha. and 462664 cu.m. cut from crop type AVERAGE, age class 33
1905 ha. and 1184910 cu.m. cut from crop type AVERAGE, age class 28
618 ha. and 299112 cu.m. cut from crop type POOR, age class 33
1684 ha. and 661812 cu.m. cut from crop type POOR, age class 28
READY

Command? CACUT

Crop area cut

Crop type? GOOD

Area (ha)? 2500

2123 ha. and 1407549 cu.m. cut from crop type GOOD, age class 23

377 ha. and 174551 cu.m. cut from crop type GOOD, age class 18

READY

Command? MASK

Mask

Crop type (for the whole forest enter *)? GOOD

Age class (for the whole crop enter 0)? 0

Crop GOOD masked.

Command? MASK
 Mask
 Crop type (for the whole forest enter **)? AVE crop type names may
 Age class (for the whole crop enter 0)? 22 be abbreviated
 Crop AVERAGE, age class 23 masked.

Command? MASK
 Mask
 Crop type (for the whole forest enter **)? POOR
 Age class (for the whole crop enter 0)? -13 minus sign indicates all
 Crop POOR, age classes 3 to 13 masked. classes younger or
 equal to the given one

Command? AREP
 Area report
 PERIOD 1980 - 1984
 Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES							TOTAL
	3	8	13	18	23	28	33	
GOOD	-4406	-2008	-1015	-1072	0	0	0	8501
AVERAGE	-5696	2596	1312	1814	-2567	0	0	13985
POOR	-5633	-2567	-1299	1666	2136	0	0	13300
TOTAL	15735	7171	3625	4552	4703	0	0	35786

Command? OCUT
 Oldest ascs cut
 Volume (cu.m.)? 1400000
 642936 cu.m. and 2136 ha. cut from age class 23 in crop type POOR
 604062 cu.m. and 1814 ha. cut from age class 18 in crop type AVERAGE
 153002 cu.m. and 728,581 ha. cut from age class 18 in crop type POOR
 READY

Command? AR only first two characters of command
 Area report names are significant
 PERIOD 1980 - 1984
 Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES							TOTAL
	3	8	13	18	23	28	33	
GOOD	-4406	-2008	-1015	-1072	0	0	0	8501
AVERAGE	-5696	2596	1312	0	-2567	0	0	12171
POOR	-5633	-2567	-1298	937	0	0	0	10435
TOTAL	15735	7171	3625	2009	2567	0	0	31107

Command? PLANT
 New plantings
 Crop type (for all crop types enter **)? AVG
 CROP TYPE AVG NOT FOUND. Please try again
 Crop type? AV
 Area (ha)? 2000
 2000 ha. planted in crop type AVERAGE

Command? PLANT
 New plantings
 Crop type (for all crop types enter **)? **
 Ha. to be planted in crop type GOOD? 2000
 Ha. to be planted in crop type AVERAGE? 500
 Ha. to be planted in crop type POOR? 0

Command? AVANCE
 INVALID COMMAND

Command? ADVANCE
 Advance to next period
 PERIOD 1985 - 1989

Command? AREP
 Area report
 PERIOD 1985 - 1989
 Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES							TOTAL
	3	8	13	18	23	28	33	
GOOD	-6506	-4406	-2008	-1015	-1072	0	0	15007
AVERAGE	-6823	5696	2596	1312	0	2567	0	18994
POOR	-5167	-5633	-2567	1298	937	0	0	15602
TOTAL	18496	15735	7171	3625	2009	2567	0	49603

Command? SAVE
 Save
 Savings control and area data. File name? OGTEMP
 WARNING! A file with this name already exists and will
 be overwritten. Do you want to try another name? NO
 Control and area data for year 1985 saved in file OGTEMP
 Do you want to save the yields with the current maskings pattern? NO
 Do you want to save the current replanting allocation? NO
 masking information is kept as negative
 signs in the yield tables

Command? REPLANT
 Replanting allocation
 Options:
 1. Display current replanting allocations
 2. Change allocations for all crop types
 3. Change allocations for selected crop types
 4. Option 1 followed by 3
 5. Read replanting data from file
 Option number? 4

FROM	TO
----	---
GOOD	GOOD
AVERAGE	AVERAGE
POOR	POOR

Enter ** to finish
 Crop type? POOR
 to be replanted into ..? AVE
 Crop type? **

Command? PCUT
 Percentage cut
 Crop type? GOOD
 Age class? 25
 1072 ha and 710736 cu.m. in age class 25 of crop type GOOD
 Percentage to be cut? 50
 536 ha. and 355368 cu.m. cut
 536 ha. remains. PCUT and CCUT are not affected by masking

Command? UNMASK

Unmask

Crop type (for the whole forest enter '')? GOOD

Age class (for the whole crop enter 0)? -18 minus sign indicates all classes older or equal to the given one
 Crop GOOD, age classes 18 to 33 unmasked.

Command? UNMASK

Unmask

Crop type (for the whole forest enter '')? **

All unmasked.

Command? COMMANDS

Commands list

COMMAND	DESCRIPTION
CCUT	Class area cut
CVCUT	Crop volume cut
OCUT	Oldest ages cut
VCUT	Volume cut
MASK	Mask
PLANT	New plantings
AREP	Area report
SSUM	Status summary
THREP	Thinning report
ADVANCE	Advance to next period
COMMANDS	Commands list

COMMAND	DESCRIPTION
PCUT	Percentage cut
CACUT	Crop area cut
RCUT	Rel.Incr.cut
ACUT	Area cut
UNMASK	Unmask
REPLANT	Replanting allocation
CREP	Crop report
CSUM	Cuts summary
SCRATCH	Scratch
SAVE	Save
END	End

Command? ACUT

Area cut

Area (ha)? 6000

2567 ha. and 1596674 cu.m. cut from crop type AVERAGE, age class 28
 536 ha. and 355368 cu.m. cut from crop type GOOD, age class 23
 937.419 ha. and 282163. cu.m. cut from crop type POOR, age class 23
 1015 ha. and 469945 cu.m. cut from crop type GOOD, age class 18
 944.581 ha. and 314545. cu.m. cut from crop type AVERAGE, age class 18
 MIN.RELATIVE INCREMENT IS NOW 7.45208 %

Command? AR

Area report

PERIOD 1985 - 1989

Areas in ha. Minus signs indicate maskings or zero yield.

CROP TYPE	AGE CLASSES						TOTAL
	3	8	13	18	23	28	
GOOD	-6506	4406	2008	0	0	0	0 12920
AVERAGE	-6823	5696	2596	367	0	0	0 15482
POOR	-5167	5633	2567	1298	0	0	0 14665
TOTAL	18496	15735	7171	1665	0	0	0 43067

Command? END

End

* 5.337 SECONDS USED

17:17:12

DISCUSSION

IFS/2 provides a convenient setup for "hands-on" exploration and assessment of management alternatives. It is easy to operate by the first-time user and is also flexible enough for a variety of applications. With some ingenuity, experienced users may find that they can use IFS in ways which are not immediately obvious or that were not envisaged when the system was designed.

For example, the product tables and thinning information, or even the basic yield tables, may contain money values (costs or returns) instead of volumes in order to prepare financial statements or evaluations. Relative increments can be used in various ways as a guide for scheduling the cut. Various thinning and pruning regimes may be represented by different crop types; in any period areas can be transferred from one crop type to another using the CCUT command (areas can be added by "cutting" a negative area). An extra crop type may also be used for keeping track of the unplanted land in each period. Files produced with the SAVE command can be manipulated by other programs.

The possible number of crop types and age classes in IFS/2 is limited only by the memory available in the computer (the ICL 2980 is a virtual memory machine, and no limits of practical significance exist in this case). However, if too many crop types and/or age classes are used it becomes difficult to keep track of the simulation, especially if no on-line hard-copy device is available. In general, the program has been written to economise on memory in preference to computing effort.

The ICL 2980 version has been adopted as the basis for documentation, being written with single-line statements, embedded comments, and line indentations in order to facilitate comprehension of the program logic. Only facilities available in most dialects of Basic have been used, so that conversion for other computers should be relatively easy. The other versions have been written making use of facilities peculiar to each computer, using multiple-line statements and eliminating unnecessary blank spaces whenever possible, in order to minimise the amount of memory used by the program. IFS/2 contains 594 statements, not counting REM (comment) statements. It is structured as a short input and control segment, and a set of subroutines which implement each of the commands. This simplifies modifications and the addition of new commands if necessary.

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REFERENCES

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- SHIRLEY, J. W. 1979: Forest modelling: New Zealand Forest Service experience. In "Mensuration for Management Planning of Exotic Forest Plantations". Elliott, D. A. (Comp.). FRI Symposium No. 20, New Zealand Forest Service, Forest Research Institute, Rotorua, New Zealand.

APPENDIX 1 — RELATIVE INCREMENTS

Relative increments are used with some of the IFS commands for establishing cutting priorities. The relative increment (RI) for a given crop/age class is the annual volume increment expressed as a percentage of the standing volume. For a 1-year period (1-year age classes) the RI would be:

$$r_i = 100 (y_{i+1} - y_i) / y_i \quad ,$$

where y_i is the yield for age class i . Then

$$y_{i+1} = (1 + r_i/100) y_i \quad .$$

In order to facilitate comparisons with rates of interest, when using age classes of width w , we define the RI so that:

$$y_{i+1} = (1 + r_i/100)^w y_i \quad ,$$

that is,

$$r_i = 100 [(y_{i+1}/y_i)^{1/w} - 1] \quad . \quad (A1)$$

RIs may be used as a guide for allocating volumes to be cut to crop types and/or to time periods.

Cut allocation to crop types

Suppose that in some time period we are required to cut a given volume from any of a number of crop types. Which is the best way of allocating this cut to the various crop types? A complete answer to this question would require an optimisation procedure looking at all time periods up to the planning horizon. The use of minimum RI priority in command VCUT, however, should in general give better results than the commonly used oldest-age priority (as in OCUT), and in most practical situations may be close to the optimum.

The allocation of the cut according to the relative increments maximises the growth of the remaining area. In order to see that this is so, assume that we cut a volume v from age class i of some crop type. If the yield is y_i , the area cut is v/y_i , and the volume lost from the next period is $v \cdot y_{i+1}/y_i$. The maximum volume at the next period is obtained then by cutting from the crop/age classes with the smallest values of y_{i+1}/y_i or, equivalently, with the smallest RIs.

The following factors may make this growth maximising allocation fall short of the optimal one in terms of present value or internal rate of return:

- (a) Different values per cubic metre for the timber from the various crop types. This may cause the priorities producing maximum volume increment to differ from those producing the maximum value increment. It could be argued that if the values differ widely the original question would not be a sensible one anyway.
- (b) The ranking of crop types according to the potential volume available in the next period may not be the same as rankings based on other future periods. This could happen in cases of very irregular demand and/or age distributions.
- (c) Differences in the values of the land released by the cut and in the annual maintenance costs. These differences are normally small relative to the crop value, and their effect can then be safely ignored.

Under the assumption of similar prices per cubic metre for all crop types, the use of the RI is equivalent to the use of the "indicating percent" for assessing relative maturity (Jørgensen 1969, pp. 58-9).

IFS compares only the RI values for the oldest non-empty age classes in each crop type. This should be sufficient, since any reasonable yield table should have RIs which decrease with age, at least for stands old enough to be harvested and except possibly for the effect of thinnings. The RI criterion may not produce the results desired if stands are being cut before the last scheduled thinning.

Cut allocation to time periods

The concept of relative increment may also be useful as a guide for distributing the cut over time. If the value per cubic metre does not change with age, the RI of a stand equals its internal marginal rate of return, known in the German and Scandinavian literature as the "indicating percent" or "weiser per cent" (Jørgensen 1969). Under conditions of constant stumpage prices per cubic metre, and neglecting the value of the land and the annual maintenance costs in relation to the value of the crop, the maximum present value is obtained by cutting the stand when the RI becomes smaller than the rate of interest (assuming that the RI decreases with age).

This can be proven as follows. The value obtained from a hectare harvested in age class *i*, discounted to age zero, is

$$V_i = p y_i / (1 + s/100)^{wi} ,$$

where *p* is the price per cubic metre, *y_i* is the yield in cubic metres per hectare for age class *i*, *w* is the age class width, and *s* is the rate of interest. *V_i* increases to a maximum and then decreases (excluding ages before the last thinning, where *V_i* might oscillate). A stand should then be harvested if *V_i* is decreasing, that is, if

$$\begin{aligned} V_{i+1} &< V_i \\ \frac{P Y_{i+1}}{(1 + s/100)^{w(i+1)}} &< \frac{P Y_i}{(1 + s/100)^{wi}} \\ \frac{y_{i+1}}{y_i} &< (1 + s/100)^w \\ (1 + r_i/100)^w &< (1 + s/100)^w \\ r_i &< s . \end{aligned} \tag{A2}$$

In practice the value of a cubic metre changes with age due to differences in piece size, and with time due to differences in demand and supply (the effect of inflation can be removed by working with "real" prices). Including also the land value *L* and the periodic maintenance cost *c*, the discounted return from harvesting 1 hectare in age class *i* now

$$\frac{p_i y_i + L}{(1 + s/100)^{wi}} - \sum_{j=1}^i \frac{c}{(1 + s/100)^{wj}} .$$

The condition for decreasing present value, *V_{i+1}* < *V_i*, is found to be

$$r_i < 100 \left(\frac{P_i}{P_{i+1}} \right)^{1/w} \left\{ (1 + s/100)^w + \frac{L}{P_i y_i} \left[(1 + s/100)^w - 1 \right] + \frac{c}{P_i y_i} \right\}^{1/w} - 100 \tag{A3}$$

Neglecting the effects of *L* and *c* and separating the price change into its two components, we can write (A3) as

$$\text{RI} < 10000 (\text{interest rate} + 100) / [(\% \text{ change of value with age} + 100) (\% \text{ change of value with time} + 100)] - 100 . \tag{A4}$$

(The effect of changing values with age may also be accounted for by using yield tables with relative values per hectare instead of cubic metres per hectare.) Notice that if prices fluctuate wildly, V_i could have multiple local maxima, so that finding a global optimum cannot be guaranteed.

These results may be used, among other things, for finding an unconstrained optimal or near-optimal cutting schedule. This can be done by estimating a "target relative increment" (TRI) for each period using (A2), (A3), or (A4) and using it with the RCUT command. If this results in an excessively irregular supply, the prices for the different periods may be adjusted accordingly, and the TRIs and cutting schedule may be recomputed. The schedule and TRIs thus obtained may be useful as a reference when exploring the effect of imposing various constraints.